

The INTERNIST-1/QUICK MEDICAL REFERENCE Project—Status Report

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INTERNIST-1 and its successor, QUICK MEDICAL REFERENCE (QMR), are computer programs designed to provide health care professionals with diagnostic assistance in general internal medicine. Both programs rely on the INTERNIST-1 computerized knowledge base, which comprehensively describes 570 diseases in internal medicine. The philosophies behind the development of each program differ. Whereas INTERNIST-1 functions solely as a high-powered diagnostic consultant program, the QMR program acts more as an information tool, providing users with multiple ways of reviewing and manipulating the diagnostic information in the program's knowledge base. At the lowest level, the program can be viewed as an electronic textbook of medicine. In addition, the QMR program has the ability to assist users with generating hypotheses in complex patient cases. The QMR program has not been evaluated formally as an information tool for practicing physicians. A preliminary study indicates that QMR's case-analysis capabilities are of potential benefit in most patients in internal medicine admitted for diagnostic evaluation.

(Miller RA, McNeil MA, Challinor SM, et al: The INTERNIST-1/QUICK MEDICAL REFERENCE project—Status report, *In Medical informatics [Special Issue]*. West J Med 1986 Dec; 145:816-822)

INTERNIST-1 and its successor, QUICK MEDICAL REFERENCE (QMR), are computer programs designed to provide health care professionals with diagnostic assistance in general internal medicine. We review the past accomplishments, current status and future objectives of our research at the University of Pittsburgh related to the INTERNIST-1/QMR project. Project objectives continue to be to extend and improve the comprehensive INTERNIST-1 medical knowledge base for diagnosis in general internal medicine and to further develop and evaluate related diagnostic information-processing programs.

The INTERNIST-1 Project

INTERNIST-1, an experimental computer-based diagnostic consultant system for general internal medicine, was developed and evaluated by Myers, Pople and Miller and co-workers.¹⁻⁷ The original goal of the project, as conceived in 1972-1973, was to develop a diagnostic computer program that could functionally mimic the reasoning of an expert clinician. Given patient data in the form of historical facts, current

symptoms, findings from a physical examination and laboratory results, the INTERNIST-1 program was designed to formulate differential diagnoses and then resolve them by asking questions. The program could make multiple and complex diagnoses in challenging patient cases.

In 1981 a retrospective evaluation of the INTERNIST-1 program was conducted using clinicopathological conference (CPC) cases published in *The New England Journal of Medicine* (NEJM).³ The study was done via retrospective case analyses so as not to subject patients to the risk of possible diagnostic errors by the computer program. The NEJM CPC cases were chosen because they contained enough detail to permit computer analysis. The diagnostic performance of the INTERNIST-1 program (for cases where the ultimate anatomic diagnoses were within the program's knowledge base) was found to be qualitatively similar to that of the clinicians caring for patients at an academic teaching hospital. The program's ability to arrive at the "correct" diagnosis, however, was not as good as that of the invited clinical expert case discussants. The study identified several deficiencies in the

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The QUICK MEDICAL REFERENCE project has been supported by grants from the CAMDAT Foundation of Farmington, Connecticut, and from the Department of Medicine of the University of Pittsburgh School of Medicine. Dr Miller is recipient of Research Career Development Award K04-00084 from the National Library of Medicine.

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ABBREVIATIONS USED IN TEXT

CPC = clinicopathological conference
 CPCS = Clinical Patient Case Simulator
 NEJM = *The New England Journal of Medicine*
 PC = personal computer
 QMR = QUICK MEDICAL REFERENCE

INTERNIST-1 knowledge base and diagnostic algorithms. The conclusions of the evaluation were that the knowledge base should be completed and that the program was not ready for use as a general-purpose diagnostic consultant system.

The QUICK MEDICAL REFERENCE Project

The Transition From INTERNIST-1 to QMR

A decade of experience spent in producing, testing and refining the INTERNIST-1 knowledge base has provided valuable insights into the difficulties associated with building and maintaining medical expert systems. Problems with the INTERNIST-1 approach to medical diagnosis⁵ have led us (R.A.M., F.E.M., J.D.M.) to develop, in 1985-1986, a successor program to INTERNIST-1: Quick Medical Reference, or QMR.^{6,8-10} QMR is a microcomputer-based source of information and consultation for diagnosis in general internal medicine. It was developed as a logical extension of the INTERNIST-1 project, with the objective to provide useful medical knowledge rapidly and conveniently to health care professionals. QMR takes advantage of many valuable aspects of INTERNIST-1 while attempting to overcome many of INTERNIST-1's deficiencies.

The INTERNIST-1/QMR knowledge base is a model for developing and maintaining an expert system knowledge base. The most significant achievement of the INTERNIST-1 project has been the creation of an extensive, computer-based repository for medical knowledge regarding the diagnosis of diseases in internal medicine. As of June 1986, the INTERNIST-1 knowledge base encompasses 572 diagnoses in internal medicine, and the system recognizes more than 4,000 possible patient findings. The knowledge base also includes more than 4,000 "links" detailing the causal, temporal and probable interrelationships among the 572 disorders. It is estimated that the number of items of information in the current but still incomplete INTERNIST-1 knowledge base is roughly 250,000. The structure and content of the INTERNIST-1 knowledge base have been described previously.^{3,7} QMR uses a modified superset of the INTERNIST-1 knowledge base as its source of medical information.

Because of the expansive domain of the INTERNIST-1 knowledge base, it was not possible to implement methods for constructing computerized medical knowledge bases used by other researchers, such as clinical data banking and "debriefing" of medical experts. For example, excellent clinical data-banking systems have been developed for coronary artery disease by Rosati and associates at Duke University (Durham, NC)^{11,12} and for various forms of arthritis and connective tissue disorders by the American Rheumatism Association's ARAMIS project.^{13,14*} Clinical data-banking techniques were not appropriate for INTERNIST-1 for two reasons. First, carefully defined entry criteria must be devel-

oped to determine which patients' data are eligible for inclusion in a clinical data bank. Developing entry criteria encompassing all diagnoses in internal medicine as a group would have resulted in meaningless generalities. Alternatively, defining entry criteria for each of the 750 diagnoses to be included in the INTERNIST-1 knowledge base would presuppose an existing knowledge base equal in depth and breadth to the INTERNIST-1 knowledge base under development.

With expert systems such as MYCIN¹⁵ and CASNET,¹⁶ methods have been developed for "debriefing" medical experts that were also not applicable to INTERNIST-1. The usual model used in medical "expert systems" for acquiring information requires that the system builders (usually computer scientists) sit down with one or more medical experts to encode the domain experts' factual and heuristic knowledge of a subject.¹⁵⁻¹⁸ INTERNIST-1's domain is so large, however, that it extends beyond the personal expertise of any small group of persons.

The INTERNIST-1 project developed its own methods for collecting and recording medical knowledge. A senior clinician (J.D.M.) who has substantial expertise in the field of medical diagnosis supervised construction of the INTERNIST-1 knowledge base. This investigator has devoted ten full person-years of effort to the project. An additional 50 to 100 persons—junior or senior medical students working under project staff guidance, fellows in computer medicine and faculty members in the Department of Medicine at the University of Pittsburgh—have worked as voluntary contributors in knowledge-base construction.

The following steps are taken during INTERNIST-1/QMR knowledge-base construction:

- Each contributor selects a disease or clinical syndrome not yet described in the INTERNIST-1 knowledge base and reviews the medical literature on the diagnosis of the disorder. One to two weeks of full-time effort are required to examine general and subspecialty textbooks, coupled with a meticulous review of about 50 to 100 relevant, primary journal articles. The goal of the literature survey is to create a list of the clinical abnormalities (findings) that have been reliably and verifiably reported to occur in patients with the given illness. The findings include demographic data and predisposing factors as well as patients' symptoms, signs and laboratory abnormalities. Medical experts who are specialists at the University Health Center of Pittsburgh and other academic centers are consulted to help resolve inconsistencies or deficiencies encountered during the literature review process.

The net result of reviewing the literature and consulting with experts is the creation of a "disease profile"—a list containing an average of 85 findings per disease (range, 25 to 250 findings). In addition to the findings in a disease profile, "linked diagnoses" are identified. Linked diagnoses are those conditions that predispose to the development of the disease under consideration, are causally related to the disease, occur more often than chance in association with the disease or temporally precede the development of the disease.

- After a draft of the disease profile has been compiled, members of the INTERNIST-1/QMR project team review the profile in a seminar led by the senior clinician (J.D.M.). Particular attention is paid during the seminar to maintaining consistency in terminology, comparing the new profile with

*See "ARAMIS (The American Rheumatism Association Medical Information System)—A Prototypical National Chronic-Disease Data Bank," by James F. Fries, MD, and Dennis J. McShane, MD, elsewhere in this issue.

similar existing profiles, reconciling disparate quantitative values from the literature and detecting omissions in the new profile. Participants in the seminar identify aspects of the profile requiring further library review or further input from experts in specialty areas.

- Once a final consensus about the new profile has been achieved, the profile is added to the INTERNIST-1/QMR knowledge base using a knowledge-base editing program.

- A second phase of checking the disease profile for accuracy and completeness then begins, using the INTERNIST-1 (and, in the near future, QMR) diagnostic system as an evaluation tool. The new profile is first tested by presenting the system with a "classic case" of a patient with the disease, constructed from a standard textbook description. The system rarely has difficulty producing the correct diagnosis. The profile is subsequently tested using more difficult CPC cases extracted from individual case reports in medical journals or from available conference proceedings at academic health centers.

Difficult cases have been presented to the diagnostic system on a regular, almost daily basis. It is estimated that over the past decade, a total of 2,000 to 3,000 such cases has been analyzed. By examining the system's inaccurate diagnoses or its failure to make a proper diagnosis, project members review and update "old" disease profiles (those already in the knowledge base). The mechanism for updating is to review the literature further and consult with experts.

- Every two to three years, the entire series of "classic" cases is again analyzed to make certain that changes in the knowledge base (made since the original case analyses) have not adversely affected performance on the cases. Previously run CPC cases are also intermittently reviewed or examined.

Rationale Behind Creating QMR

A major problem with INTERNIST-1 was that the program was designed to serve as a high-powered diagnostic consultant system for challenging cases in internal medicine. The philosophy underlying INTERNIST-1 was that the program should be able to perform as if it were an expert consultant. This model of diagnostic consultation has been important in the subsequent development of the comprehensive INTERNIST-1 medical knowledge base and the related INTERNIST-1 diagnostic program. This model, however, addresses only a small portion of the information needs of physicians.¹⁹ The INTERNIST-1 program did not allow its users to have direct, immediate access to the information in the INTERNIST-1 knowledge base.

In contrast, QMR has been developed in an attempt to meet the practical needs of clinical medicine. The philosophy underlying QMR is that the program should be able to augment a health care professional's diagnostic accuracy and efficiency by providing convenient access to information and a variety of useful tools for managing diagnostic information. The QMR program treats the computer user as an active information-seeking participant, not a passive one, as was the case in INTERNIST-1. In this regard, QMR is similar in purpose to the RECONSIDER program developed by Blois and colleagues.²⁰

Another problem with INTERNIST-1 was that the program engaged the user in a laborious, time-consuming dialogue lasting 30 to 75 minutes. This form of interaction was

necessary to describe and evaluate a complex patient case comprising 50 to 180 positive and negative findings. Busy physicians, however, can rarely afford this amount of time to interact with a computer program. The problem was compounded by the INTERNIST-1 program's lack of a user-friendly interface. Unless the user entered case findings using the rigid INTERNIST-1 terminology, the program could not process the information. QMR has been designed to provide answers in seconds, rather than minutes or hours.

Whereas INTERNIST-1 was implemented on a main-frame computer with restricted dial-up access, QMR runs on widely available microcomputers. Quick Medical Reference has been written in Turbo Pascal (Borland International). It runs on any system compatible with an IBM personal computer (PC) meeting the following requirements: MicroSoft PC-DOS or MS-DOS disk operating system (version 2.1 or higher), 512K or more of random access memory and at least five megabytes of available space on a fixed (hard) disk. The program runs most efficiently on the IBM-PC-AT (IBM Personal Computer, Advanced Technology model) or compatible 80286-based machines.

Key Features of QMR Program Function

The QMR completer. An important goal of QMR's design is to enable novice users to enter patient findings or diagnoses with ease. QMR's user interface attempts to minimize the amount of typing required from a user and attempts to reduce problems due to spelling errors. A "completer" program has been developed to allow users to enter, quickly and efficiently, the names of the various patient findings and diagnoses known to QMR. The QMR completer allows users to pick a few key words from the medical terms they want to enter and then to type the first few characters of each of those words. The "completer" functions independently of word fragment order—the user obtains the same results no matter how the group of word fragments is typed into QMR. For example, a user wanting to enter the finding "abdominal tenderness, right lower quadrant" could type any of the following:

abd ten low
r l q tender [spaces between r, l and q essential]
lower quadrant

After receiving word fragments as input, the QMR completer displays, within a few seconds, a menu (numbered list) of the possible INTERNIST-1/QMR vocabulary terms matching the fragments entered. Only one or two additional keystrokes are required from the user to select the desired vocabulary item by its menu number.

QMR as a low-level information retrieval tool. QMR contains two useful, straightforward information-retrieval options: (1) "Display a disease profile's findings and links" and (2) "Display the differential diagnosis of a single finding." The disease profile summarizes in a few seconds what would take a person one to two weeks to discover by a primary literature review about the diagnosis of the disease. The findings reliably reported to occur in patients with a given disorder and a list of the linked (related) diagnoses for the disorder are included in the display. Thus, one can easily review a profile of any of the 572 diseases currently in the QMR knowledge base.

The QMR option, "Display the differential diagnosis of a

single finding," allows a user to display the list of possible diagnoses associated with any of the more than 4,000 findings in the knowledge base. In the display, the differential diagnosis is sorted by descending positive predictive value—that is, the most prominent causes of the finding are listed first. The differential diagnosis lists are comprehensive because they are derived from the disease profiles. For example, the differential diagnosis of the finding "abdominal pain, right upper quadrant" contains 131 diagnoses; the differential diagnosis of "chest pain, substernal, at rest" includes 34 diagnoses, and the differential diagnosis of "cyanosis of mucous membranes" includes 103 diagnoses.

QMR as an intermediate-level information management tool. A physician seeing a patient can usually quickly determine that the patient's main pathologic condition involves a particular organ system. The patient, however, may show a finding that does not fit conceptually with disease in that organ system. The QMR option, "Find associations of a finding to a group of diagnoses," can be used to connect a seemingly unrelated finding to disease in a specified organ system. For example, the user can pose the question, "How can massive splenomegaly be related to liver and biliary tract disease?" and determine from the program a list of possible mechanisms. Both direct causes—liver diseases that themselves cause massive splenomegaly—and indirect causes—diseases of the liver and biliary tract that are associated with other diseases that cause massive splenomegaly—are displayed.

For the given example, QMR indicates that the following liver and biliary tract disorders are directly associated with massive splenomegaly: hepatosplenic lymphoma, presinusoidal portal hypertension and sinusoidal or postsinusoidal portal hypertension. Of the liver and biliary tract disorders indirectly related to causes of massive splenomegaly, QMR lists, among others, hepatic amyloidosis as a complication of systemic amyloidosis, hepatic histoplasmosis as a complication of disseminated histoplasmosis, secondary fatty liver as a complication of Felty's syndrome and either hepatic vein thrombosis or cholelithiasis as a complication of paroxysmal nocturnal hemoglobinuria.

QMR also contains a "case analysis" option that can be used in two modes. The first mode is for analyzing simple cases characterized by a dozen or fewer findings. Here a user seeks confirmation that a complete differential diagnosis has been constructed. The second mode is for complex, CPC-type cases in which an extensive patient evaluation has already been done but for which there is no readily apparent diagnosis. Here a user desires diagnostic assistance in determining ways to put the multiple components of a case into logical perspective.

During case analysis, QMR provides several options. In simple cases involving a few positive patient findings, it is likely that at least several diagnoses can individually explain all of the positive findings. After entering the findings of a simple case, the user can indicate, "Examine the single diagnoses explaining all findings." QMR will then list all diagnoses in the QMR knowledge base fully consistent with the positive patient findings entered. All diagnoses explaining all the positive findings are displayed, independent of their prevalences.

Another option, "Review single diagnoses per INTERNIST-1 approach," allows a user to list the most attractive

diagnoses based on a quasi-probable rating scheme (see below). An additional QMR option identifies pairs of closely related diagnoses that in combination can explain all of the patient's findings. For the identified pairs, each diagnosis of a given pair explains only a portion of the patient's findings—but together each pair explains all findings.

QMR as a high-level information management utility. The QMR case-analysis mode allows a user to enter up to 95 positive and 95 negative findings (190 total findings) from a case. Positive findings are those present in a patient's case; negative findings consist of pertinent abnormalities looked for but absent in the patient. For complicated CPC-type cases, the user can employ a series of advanced case-analysis functions. QMR utilities exist to generate diagnostic hypotheses of various forms, to allow the user to assert one or more diagnoses as being present in a patient and to then allow QMR to process the residual unexplained findings and critique the strengths and weaknesses of any user-entered hypothesis. After storing a patient case on a disk file, the user can later retrieve the information to add and analyze additional findings.

In complex cases, it is extremely unlikely that any one (or even two) diagnoses will explain all of a patient's findings. To analyze such difficult cases, QMR provides two methods for generating and ranking hypotheses: review of single diagnoses per the INTERNIST-1 approach, and display of possible global case overviews. Ranking hypotheses per the INTERNIST-1 algorithm allows a user to examine the best-rated diagnoses as determined using the quasi-probable INTERNIST-1 scoring scheme.³ Hypotheses are ranked by the positive predictive values of the observed findings for the diagnoses, the ability of each diagnosis to explain the clinically important findings in a case, the presence of previously asserted (concluded) diagnoses related (by links in the knowledge base) to a hypothesis under consideration and the negative weight (against a diagnosis) due to findings that commonly occur in the illness being absent in a patient.

In complex cases, there are often many disease states simultaneously present in a patient. If the diseases are related to one another (as represented by the disease links in the knowledge base), then the QMR program can also offer global hypotheses that attempt to tie the entire case together. The QMR "global case overviews" option operates under the assumption that a patient has several pathophysiologically related disorders. Each "global overview" represents one of the many possible ways of logically interrelating individual diagnoses to form a more complete picture of a patient's illness.

In the case-analysis mode, a user can request that the QMR program "critique" diagnostic hypotheses suggested by the user. Essentially, after entering pertinent lists of positive and negative patient findings, the user can say, "What about disease X as a possible diagnosis?" where disease X might be any one of the 572 disorders profiled in the QMR knowledge base. The ensuing critique will explain what evidence in the patient's case supports the suggested diagnosis, what clinical case findings are not explained by the diagnosis and which negative case findings are strong evidence against the suggested diagnostic hypothesis. In the critiquing mode, QMR also generates a list of diagnoses related to the user's suggested diagnosis. These related diagnoses merit consider-

ation because they may enhance the attractiveness of the user's suggested diagnosis—the related diagnoses often account for some of the patient findings not directly explained by the user's diagnosis.

During a case analysis, the user can "assert" that a particular diagnosis is present in the patient. The QMR program will then remove all findings explained by the asserted diagnosis from further consideration. This allows the user to reexamine the residual findings in the case in a newly created context. Diseases related to the asserted (concluded) diagnosis are subsequently given extra consideration. Conclusion of a diagnosis is not irreversible; a "retract asserted hypothesis" option provides for change. The "assert a diagnosis" option is helpful in analyzing cases where more than one independent (unrelated) diagnosis coexists in the same patient.

Figure 1 summarizes a study estimating the possible impact of QMR's case-analysis capabilities on the practice of inpatient general internal medicine. Over a six-week period, 36 of 116 patients serially admitted to two general medical wards were deemed by the ward team (attending physician, house staff and students) to present diagnostically significant problems. QMR analysis of those cases was found to be helpful in 72% of the cases.

Future Directions for QMR

The Quick Medical Reference project has provided us with an opportunity to improve on several aspects of the INTERNIST-1 program. QMR has broadened the scope of the project's objectives. INTERNIST-1 provided only a diagnostic consultant capability for complicated case analyses. QMR represents an "information tool" that can serve as an electronic textbook, an intermediate-level consultant or a sophisticated analytic tool. These features extend the capabilities of the original INTERNIST-1 program. In addition, QMR has shown that many of the "expert system" characteristics of the INTERNIST-1 program could be implemented on a microcomputer in a manner that would run at least as fast as the original mainframe version of the INTERNIST-1 program.

The QMR program has so far been under development for only a year. The program and its capabilities are evolving rapidly on several fronts. Projects related to QMR currently planned or in progress include

- Improving the QMR program itself.

The INTERNIST-1/QMR knowledge base will be further completed, tested and refined. The authors estimate that an additional 180 disease profiles must be added to the existing 572 profiles to encompass the breadth of expertise expected of general internists.

The QMR user interface will be improved by adding a "natural language" processing capacity to deal with synonyms for terms in the QMR vocabulary entered by users.

An improved question-generating capability for use during case analysis will be implemented. In addition, a feature to allow users to specify a suggested diagnosis that must be taken into account during case analysis will be developed.

Improved on-line help capabilities and better user training materials will be developed for QMR.

- Incorporating the National Library of Medicine's medical subject heading terms into the INTERNIST-1/QMR

knowledge base is a first step in being able to provide relevant literature references regarding diseases and findings. This will also allow investigation of a semiautomated literature review as a means of updating the knowledge base.

- Creating educational applications for the INTERNIST-1/QMR system. QMR itself will be evaluated as a tool for medical education of students and house officers. The Clinical Patient Case Simulator (CPCS) is a mainframe-based program written by one of us (R.A.M.) to construct artificial patient cases from a specialized form of the INTERNIST-1 knowledge base.²¹ The artificial patient cases can be used for teaching medical diagnosis. The CPCS will be converted to run on microcomputers in parallel with the QMR knowledge base.

- Evaluating QMR in the future. Studies of QMR's user acceptability, its relevance to clinical practice (see Figure 1) and its effect on clinical outcomes will be carried out as the program is further developed.

Conclusion

Several important questions remain to be answered regarding medical expert systems. First, is it possible to develop academically oriented, high-quality computerized medical knowledge bases for widespread use? We believe the answer to this question is "yes" but, as described above, the costs in time, money and dedication are substantial. Second, if it is possible to develop such knowledge bases, do practical methods for their maintenance exist? Again, we believe the answer to this question is yes. Unfortunately, the development of semiautomated or fully automated updating techniques for medical knowledge bases is largely unexplored; labor-intensive manual methods are required at present. Third, can diagnostic computer programs become efficient, inexpensive and user friendly enough to compete with the current "gold standard" for diagnostic assistance, a phone call to a respected colleague? It is our opinion that powerful microcomputers now available may eventually provide diagnostic assistance at an affordable cost in time and money. The definitive answer to this question awaits further development and testing of programs like QMR. A fourth question is whether physicians will be willing to use even "perfect" computer programs in routine practice. Few diagnostic programs have reached a stage of development to undergo serious field testing to answer this question. Finally, there are important legal and ethical issues related to the use of computer programs in clinical practice. Should anyone be allowed to use a medical computer program? Who will be held legally liable if the programs give mistaken medical advice? Will the legal "standard of care" come to include the use of medical computer programs, forcing physicians to adopt a new technology? Many such perplexing questions remain to be answered.²²

Initially QMR was developed to provide rapid and convenient access to the contents of the INTERNIST-1 medical knowledge base. More advanced information-processing capabilities have been added through QMR's case-analysis mode to help work through complicated case problems. As noted above, clinical validation of QMR has not yet been attempted. More detailed studies of the type described in Figure 1 will be required. Thus, QMR cannot be made available to health care professionals on a routine basis at

A prospective evaluation was recently conducted to examine the clinical usefulness of the QMR case-analysis mode in the setting of inpatient general internal medicine. Two of us (M.A.M. and S.M.C.) studied a total of 116 patients consecutively admitted over a 6-week period to two general medicine wards at University of Pittsburgh teaching hospitals. Only cases admitted for diagnostic evaluation were submitted for computer analysis. These included both diagnostic dilemmas and routine problems such as evaluation for anemia. Excluded from QMR analysis were admissions for such purposes as chemotherapy or terminal care where no diagnostic issues were under consideration. A total of 36 out of the 116 cases were subjected to computer analysis. Thus, 80 of the 116 cases were deemed not to be diagnostic problems. The utility of the simple information-retrieval capabilities of QMR—such as providing a disease profile for review purposes—was not evaluated in these 80 patients.

Pertinent historical items, physical findings and laboratory values from each patient case were entered by an experienced QMR user via the program's case-analysis mode. A differential diagnosis list was generated by the computer for each case, with the diagnoses sorted in descending order of likelihood. This ranking was then compared with the differential diagnosis determined by the ward team (attending physician, house staff and medical students) on teaching rounds the day after they had independently completed their own rankings. The final discharge diagnoses, when available, were used to determine the accuracy of the initial impressions of the ward team and the QMR program.

The 2 sets of initial differential diagnoses (ward team's and QMR's) were compared for similarities and differences. In 21 of the 36 patients subjected to computer analysis, the major clinical diagnosis under consideration was the same as the top-ranked QMR-generated diagnosis. For these 21 cases, review of the computer's analysis modified the clinicians' planned approach to the case in 6 instances. In 2 patients, the clinicians reordered their ranking of possible diagnoses after reviewing the QMR differential diagnosis; in 2 patients the clinicians discarded diagnoses they had been considering after reviewing the QMR differential diagnosis and in 2 patients the clinicians added diagnoses suggested by QMR to their working differential diagnoses.

In 15 patients, the ward team's working hypotheses were different from QMR's differential diagnosis. Of these 15 cases, QMR's suggested diagnosis was in fact confirmed at the time of discharge in 3 patients. In 4 of the 15 cases, the final diagnosis remained unknown so no comparison was possible. In these 4 cases computer analysis neither added to nor detracted from the clinical evaluation. In 8 of the 15 cases, the QMR-suggested diagnoses did not match the final discharge diagnoses. In 1 of the 8

cases, both the ward team's and the computer's diagnoses were incorrect. In the remaining 7 patients, the clinicians' diagnoses were accurate and QMR's diagnoses were not appropriate. In 2 of these 7 cases, the diseases under consideration were contained in the knowledge base of QMR, and thus the performance of QMR could be categorized as misleading. In the remaining 5 of the 7 cases where the QMR's diagnoses were in error, a major component of the correct differential diagnosis had not yet been included in the QMR knowledge base. The disease processes not known to the program included osteomyelitis, superior vena cava syndrome and the syndrome of inappropriate antidiuretic hormone secretion occurring as complications of bronchogenic carcinoma and 3 cases with extrinsic spinal cord compression from known neoplastic disease.

In addition to the 5 cases where the major clinical diagnosis under consideration was missing from the QMR differential because of a limited knowledge base, there were 4 other cases analyzed where a complete differential diagnosis was not generated by the computer because of a limited knowledge base in the program. In all 4 cases, the major diagnosis was known to the computer and was given top priority in the QMR differential diagnosis. An important competing diagnosis, however, was not identified because of insufficient knowledge. In 1 of these cases, the computer also added a diagnosis to the clinicians' differential that they had not previously considered.

Overall, when prospectively used to evaluate 36 diagnostically significant patient cases, QMR was deemed to be "very helpful" to the ward team in the management of 12 patients. It added diagnoses in 5 cases, reordered the differential diagnosis in 2 cases, ruled out diagnoses in 2 cases and suggested the correct diagnosis in 3 cases in which the clinicians were incorrect. The QMR analysis was rated "helpful" in an additional 14 patients for whom the program confirmed the ward team's major clinical diagnoses. In 2 cases where the diagnoses remained unknown at the time of discharge, QMR analysis was rated as "unhelpful" or "misleading" by the ward team. In the remaining 8 of the 36 patients, the QMR analysis differed from the validated discharge diagnoses. In these 8 cases, the computer was in error and potentially misleading. In 6 of the 8 cases, however, QMR missed the correct diagnoses because of an insufficient knowledge base rather than an intrinsic error in the medical decision-making system. In summary, in a prospective evaluation of patients consecutively admitted to general medical wards, QMR case analysis was found to be helpful in 26 of 36, or 72% of the diagnostically significant cases. The bulk of the errors in QMR case analysis, moreover, can be attributed to limitations of the knowledge base, which is still under development.

Figure 1.—A prospective evaluation of the potential relevance of Quick Medical Reference (QMR) to inpatient general internal medicine.

this time. After further development and careful testing of its capabilities during the next few years, we hope to release QMR to the general medical community. Its use should help physicians to be more efficient, more reassured and more effective in the diagnosis of problems and in the care of patients.

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